Development of Bioformulation and its Application against Management of Thrips and Root Rot Disease of Mulberry, *Morus alba*

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INTRODUCTION

Microorganisms are a rich source of new metabolites with a wide variety of biological activities and some of them display significant practical applications. Earth is the planet of insects, as they are found in almost every corner of the earth. There exist more than one million insect species than any other animal species comprising 72.8% of all animals (Dillon and Dillon, 2006). One of the major features of insects is their extraordinary diversity in terms of numbers and morphological forms. In addition to their ability to survive in different ecological conditions, insect gut is a reservoir of complex microbial communities. These contribute to the host nutrition, growth, development and physiology. Apart from that they also play a key role for the stimulation of...
the immune system and resistance against the invading pathogens (Kehinde et al., 2011). The protective effect of the gut bacteria are termed as bacterial antagonism which is a significant component of host defense against pathogens. Gut bacteria has been documented to show antagonistic activity against pathogenic bacteria and fungi.

Function for biomass deconstruction from insect symbiotic microbiota is well characterized. Both herbivore insects and symbiotic microbes can secrete cellulytic enzymes for biomass deconstruction and hydrolysis (Ohkuma, 2003; Tokuda and Watanabe, 2007; Warnecke et al., 2007; Sun and Zhou, 2009). It has been controversial about which plays a more important role for biomass deconstruction, the symbionts or insect host itself. Despite the controversy, the importance of symbiotic microbes for biomass deconstruction has recently been established by various genome-level studies. In the present study, isolated the gut bacteria as of silkworm and developed the bio formulation against pest and disease of mulberry (Morus alba).

Materials and Methods

Molecular identification of antagonistic bacterial isolates

Among these six antagonistic bacterial isolates, two isolates which were found to be promising. They were subjected to further molecular studies done by Merck Millipore, Bangalore. The genomic DNA was extracted using geneiUtrapure™ bacterial genomic DNA purification kit KT162 Cat# 612116200021730 and stored at -20 °C.

Each strain was identified to the genera by amplifying the 16S rDNA fragment by polymerase chain reaction (PCR) using specific primers of Forward primer - 5’- AGAGTTTGATCMTGGCTCA - 3’ and Reverse primer - 5’ – TACGGYTACCTT GTTACGACTT-3’. The 1.5kb fragment of 16S rDNA was amplified in a thermocycler under the following conditions: initial denaturation at 94°C for 5 min; 35 cycles of 94°C for 30 sec; 55°C for 30 sec; 72°C for 1.30 min and final extension at 72°C for 10 min. The PCR reaction mixtures (50 µl) contained 100 ng of each primers, genomic DNA 20 ng, dNTP mix (2.5Mm each), tag buffer A (10X) 1x, taq polymerase enzyme 3U and double distilled water to make up the volume 50 µl. The PCR products were analyzed using electrophoresis on 1 per cent agarose gel and marked using 500bp DNA ladder as the size marker. After migration, gels were exposed to ultraviolet light (UV) to locate the amplified bands. The sequences were compared for similarity with reference sequences in genomic databases using BLAST.

Production and optimization of Bacillus subtilis

Bacillus subtilis was grown on nutrient agar for 24 h, 48 h, 72 h and 96 h of cultivation on an orbital shaker at 150 rpm at 300°C. Both viable and heat - resistant spore counts were determined. For heat - resistant spore counts, cultures were heated at 80°C for 15 min to kill any vegetative cells present. Spores were then subsequently enumerated by plating aliquots of serial dilutions onto nutrient agar media which were incubated for 3 days at 30°C.

Multiplication of sporulation

Nutrient broth medium was used as the basal medium on which more number of spores multiplied under sterilized condition. Total viable spore count and the spore percentage were determined after 72 h of cultivation as described before.
Preparation of Bacillus subtilis spores

*Bacillus subtilis* was grown on a modified nutrient medium supplemented with a mixture of MnSO$_4$, CaCl$_2$, ZnSO$_4$ and KCl at a concentration of 500 µg/mL for 3 days on an orbital shaker at 150 rpm till the maximum spore yield was produced. These were harvested and subsequently washed by repeated centrifugation at 10,000 rpm for 20 min at 4°C and resuspended in sterile distilled water (Warriner and Waites, 1999). Finally, the spore pellet was re-suspended in sterile distilled water and used as active material in different formulations. The final spore titer was ≥10^8 CFU/mL.

Formulation of Bacillus subtilis

The inert carrier used in the formulations was talc. For 1% carboxymethylcellulose (CMC) as binder, traces of sodium benzoate as stabilizer, 15% CaCO$_3$ as buffer and 0.25% of different enrichment materials were incorporated. The enrichment materials incorporated to be tested were: glucose, sucrose, mannitol, yeast and peptone. The inert carriers, enrichment and additive materials were mixed and sterilized by autoclaving. Twenty mL of spore suspension was added into them, mixed well under aseptic conditions, and then the mixtures were air dried in a laminar flow chamber for 48 hours. After drying, one g sample was removed for initial population counts. Powder formulations were then placed in plastic petri plates, sealed with parafilm, stored at room temperature and sampled for viability assessment.

Viability assessment

In the viability assessment, population counts of bacteria among various formulations were determined by serial dilutions from formulations and plated in triplicate on nutrient agar, and the CFU per gram of formulation were enumerated at monthly interval for 6 months.

Evaluation of formulation against sericulture pest and disease

Bioassay study against mulberry pest of thrips

*Bacillus subtilis* isolates were incubated at 30°C for 72 h in nutrient broth. After incubation, stock culture was diluted at different percentages (40, 60, 80, and 100) by adding sterile phosphate-buffered saline, and 5 mL of the culture was centrifuged at 6,000 rpm for 10 min. The pellet was re-suspended in 5 mL of sterilized phosphate-buffered saline and it was used for bioassays. Bioassays were carried out in two sets of pot cultured mulberry plants maintained separately in Mylar cages. Bacterial cultures were sprayed on a set of mulberry plants at different concentration and control was maintained separately. Thrips were collected from the infested mulberry garden and released by camel brush at 100 thrips per plant in treated and control pot cultured mulberry plants. The mortality of insects was recorded at 1st, 3rd, 7th, 10th days. Mortalities were corrected by Abbott’s formula.

Screening of bacterial isolates for biocontrol potency against *M. phaseolina* and *F. oxysporum* by dual culture technique

The six isolates of bacterial culture obtained in this study were tested against the *M. phaseolina* and *F. oxysporum* by the dual culture technique. The mycelial disc of 5mm diameter of bacterial isolates from a three-day old culture was placed one side 0.5 cm away from the edge of the petriplate containing PDA media, and the disc of *M. phaseolina* and *F. oxysporum*. A three-days old culture was placed on the opposite side, 6 cm apart from the bacterial streak. The plates were incubated at 24 ± 2°C for one week. The
plates were observed at regular intervals for the radial growth of the pathogen and also the antagonistic bacterial isolates. The distance of inhibition zone was measured to the nearest whole millimeter.

The radial mycelial growth of the pathogen and per cent reduction over control was calculated by using the formula as follows:

\[
\text{Per cent inhibition over control} = \frac{C - T}{C} \times 100\%
\]

Where,

\(C\) – mycelial growth of pathogen in control
\(T\) – mycelial growth of pathogen in dual plate

Results and Discussion

Development and evaluation of bioformulation for pest and disease management

Molecular identification of antagonistic silkworm gut bacteria

The isolates SGB1 and SGB2 were identified by 16S rRNA gene sequence data analysis. The identification of the isolate was confirmed commercially by the Merck Millipore, a division of Merck KGaA, Darmstadt, Germany (Report enclosed). A BLAST search of the database indicated a close genetic relationship to other isolates of Bacillus sp. The phylogenetic tree was constructed and tree visualization was done by Molecular Evolutionary Genetics Analysis (MEGA) software version 4.0 (Plate 1a and 1b). Partial 16S rRNA gene sequence data analysis of strain SGB1 and SGB2 showed high arrangements between traditional and molecular identification as established by earlier traditional characterization, and the isolate was finally identified as B. subtilis and B. tequilensis.

Development of commercial product

Formulations generally composed of the active material must be preserved or maintained in viable condition to produce its biological effect; the carrier material may or may not include the incorporation of enrichment materials or additives.

Generally, amendments can be grouped as either carriers (fillers, extenders) or amendments that improve the chemical, physical, or nutritional properties of the formulated biomass (Schisler et al., 2004). The active material is mixed with carrier materials such as water, talc or others to make the formulation safer to handle, easier to apply and better suited for storage. In some formulations, enrichment materials comprising of nutrient-rich medium such as, molasses, trehalose, maltose and sucrose are incorporated to further enhance the viability of core (active) materials (Brar et al., 2006; Tu and Randall, 2005).

The commercial use of biocontrol agent requires inoculum that retains high cell viability and easily be transported and applied. The aims of formulating viable cells are to ensure that adequate cell viability is sustained to increase the efficacy of the cells and to facilitate the delivery and handling processes (Filho et al., 2001). For commercialization, a long shelf-life is an advantage for any inoculant (Fages, 1990 and 1992).

In the present study, total viable cell counts (TVC), spore count, spore percentage, enhancement of sporulation, effect of different carriers and amendments on survival of bacteria was carried out the highest value of total viable count was recorded (420 x 10^8 CFU/ml) after 72 h followed by 175 x 10^8 CFU/ml at 48h compared to 24 and 96 h. Heat-resistant spore count was 100 x 10^8
CFU/ml after 72 h of inoculation when compared to other durations. The sporulation percentage of *B. subtilis* (7.69, 10.20, 23.8 and 37.30) was found to gradually increase from 24 h to 96 h respectively. The total viable count and heat resistant spore count of *B. subtilis* was significantly higher at 72 h interval than other hour intervals (24h- 65 TVC×10⁸ CFU/ml and 5 HRSC×10⁸ spore/ml; 48h - 175 TVC×10⁸ CFU/ml and 18 HRSC×10⁸ spore/ml and in 96h - 75 TVC×10⁸ CFU/ml and 28 HRSC×10⁸ spore/ml) (Table 1).

As shown from table 2, incorporation of metals to the basal sporulating media generally increase the sporulation process, total viable counts were higher (190×10⁸ CFU/ml) in mixture followed by MnSO₄ (145×10⁸ CFU/ml) except for CaCl₂ (78 ×10⁸ CFU/ml) and this might be due to increasing of osmotic pressure of media which have positive effect on sporulation process, which is supported by the fact that certain transition metals including zinc (Zn) and manganese (Mn) in a complex sporulation medium stimulated spore formation in certain strains of *Clostridium botulinum*, but sporulation was drastically decreased by the addition of copper (Cu) to the medium (David et al., 1990) and present results are shown in figures 2a and b.

Medium containing 500 µg/ml of MnSO₄, ZnSO₄ and KCl showed the highest values of both total viable count and heat-resistant spore count compared with other concentrations tested and this is in agreement with a fact that there is a correlation between growth rate and spore yield (Osadchaya et al., 1997).

Varying the metal concentration in the sporulation media is known to influence the thermal- resistance spores due to induction of genes coding for the two small acid soluble proteins earlier during sporulation in the media that contained higher metal concentrations (Oomes and Brul, 2004).

In talc formulations, bacterial populations declined steadily over time, the bacteria survived even up to 180 days of storage with different percentage although the population declined from 30 days of formulation. Bacterial population gradually declined from 30 days onwards and continued.

The number of viable cell count was 190×10⁸ CFU/g on 30th day, 175×10⁸ CFU/g on 60th and 90th days after storage of talc formulation. The viable cell counts were 150×10⁸ CFU/g on 150 and 180 days after storage. The highest survivable percentage (88.3%) of viable cell count was recorded on 30th day. On 60th and 90th day the survivable percentage of viable cell count was 81.4 per cent. The survivable percentage was 69.7 per cent on 150 and 180 days (Table 3).

Recent studies on beneficial rhizobacteria have investigated the efficacy of powder formulations in combination with methylcellulose and xanthan gum (Kloepper and Schroth, 1981; Suslow, 1982). Among the formulations, enrichment materials proved to be the most useful as highest number of viable cells were recovered. These are in agreement with previous research which showed that high molecular weight (C6 to C12) compounds such as sucrose and trehalose enhanced survival of bacteria in dried biopolymers (Ilyina et al., 2000).

**Evaluation of bioformulation against pest and disease of sericulture field**

Bioformulation was developed to use against mulberry pest- thrips, *M. phaseolina* and *F. oxysporum* by dual culture technique. Inhibition on antifungal assay against *B. bassiana, M. anisopliae, M. phaseolina,*
*oxysporum*, and antimicrobial activities against silkworm pathogens were also studied.

**Effect of antagonistic bacteria against mulberry pest- thrips**

The results of the experiment showed that different percentages of bacterial culture were tested against mulberry thrips (Table 4). Population of thrips gradually reduced from first day (60 nos/plant) to 10 DAT (12nos/plant) with maximum reduction seen in 100 per cent culture filtrate, followed by 80, 60 and 40 per cent concentrations. On 10 DAT, thrips population was lowest (18 nos/plant) at 80per cent when compared to 60 and 40 per cent culture filtrates. This trend was observed as the population increased with decrease in the concentration i.e., 23 nos./plant at 60 per cent and 33 nos./plant at 40 per cent concentration respectively. Highest percentage of reduction over control was observed in 100per cent (86.95%) followed by 80 per cent (80.43%), 60 per cent (75.00%) and 40 per cent (64.13%).

**Table 1** Total viable cell counts, spore count and spore percentage of *B. subtilis*

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Nutrient Agar Media</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TVC ($\times 10^8$ CFU/ml)</td>
</tr>
<tr>
<td>24</td>
<td>65</td>
</tr>
<tr>
<td>48</td>
<td>175</td>
</tr>
<tr>
<td>72</td>
<td>420</td>
</tr>
<tr>
<td>96</td>
<td>75</td>
</tr>
</tbody>
</table>

TVC: total viable count; HRSC: Heat-resistant spore count

**Table 2** Influence of metals on sporulation of *B. subtilis*

<table>
<thead>
<tr>
<th>Metals added at 500 µg/ml</th>
<th>Total viable count ($\times 10^8$CFU/ml)</th>
<th>Heat-resistant spore count ($\times 10^8$spore/ml)</th>
<th>Spore percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnSO4</td>
<td>145</td>
<td>76</td>
<td>52.4</td>
</tr>
<tr>
<td>CaCl2</td>
<td>78</td>
<td>25</td>
<td>32.0</td>
</tr>
<tr>
<td>ZnSO4</td>
<td>110</td>
<td>45</td>
<td>40.9</td>
</tr>
<tr>
<td>KCL</td>
<td>89</td>
<td>56</td>
<td>62.9</td>
</tr>
<tr>
<td>*Mixture</td>
<td>190</td>
<td>183</td>
<td>96.3</td>
</tr>
<tr>
<td>Control</td>
<td>93</td>
<td>31</td>
<td>33.3</td>
</tr>
</tbody>
</table>

*A mixture composed of each of the following: µg/mL of MnSo4, CaCl2, ZnSo4 and KCL*
### Table 3: Effect of carrier and amendments on survival of bacteria in powder formulations

<table>
<thead>
<tr>
<th>Sampling(days)</th>
<th>0 day</th>
<th>30 day</th>
<th>60 day</th>
<th>90 day</th>
<th>120 day</th>
<th>150 day</th>
<th>180 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc (x10^8 CFU/g of formulation)</td>
<td>215</td>
<td>190</td>
<td>175</td>
<td>175</td>
<td>160</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>*Survival (%)</td>
<td>-</td>
<td>88.3</td>
<td>81.4</td>
<td>81.4</td>
<td>74.4</td>
<td>69.7</td>
<td>69.7</td>
</tr>
</tbody>
</table>

*Per cent survival of formulation was determined as follows:

\[
\text{Per cent survival} = \frac{\text{CFU/g of formulation at sampling}}{\text{CFU/g of formulation at beginning of experiment}} \times 100
\]

### Table 4: Effect of antagonistic bacteria against mulberry pest-thrips

<table>
<thead>
<tr>
<th>Antagonistic organism</th>
<th>Culture filtrate (%)</th>
<th>Reduction in population</th>
<th>ROC %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1(^{st}) day</td>
<td>3(^{rd}) day</td>
<td>7(^{th}) day</td>
</tr>
<tr>
<td>Bacillus subtilis</td>
<td>40</td>
<td>85</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>69</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>64</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>60</td>
<td>46</td>
</tr>
<tr>
<td>Control</td>
<td>100</td>
<td>96</td>
<td>94</td>
</tr>
</tbody>
</table>

Reduction over control per cent (ROC) = \(\frac{\text{Control} - \text{Treatment}}{\text{Control}}\) \times 100

### Table 5: Inhibition of different bacterial isolates against *Macrophomina phaseolina* and *Fusarium oxysporum*

<table>
<thead>
<tr>
<th>Mycelial growth of the pathogen (mm)</th>
<th>Bacterial isolates</th>
<th>Per cent inhibition over control</th>
<th>Inhibition zone (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. phaseolina</td>
<td>B. subtilis</td>
<td>50.00(± 0.10)</td>
<td>13(± 0.20)</td>
</tr>
<tr>
<td>M. phaseolina</td>
<td>B. tequilensis</td>
<td>44.44(± 0.20)</td>
<td>11(± 0.11)</td>
</tr>
<tr>
<td>F. oxysporum</td>
<td>B. subtilis</td>
<td>30.00(± 0.13)</td>
<td>9(± 0.14)</td>
</tr>
<tr>
<td>F. oxysporum</td>
<td>B. tequilensis</td>
<td>23.33(± 0.20)</td>
<td>7(± 0.18)</td>
</tr>
<tr>
<td>Control (90)</td>
<td></td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean inhibition zone (mm) ± S.D of three replicates.
Plate 1a. Phylogenetic tree of 16S rRNA gene sequences of silkworm gut bacteria (SGB1). The scale bar represents 1 substitutions/base position.

Plate 1b. Phylogenetic tree of 16S rRNA gene sequences of silkworm gut bacteria (SGB2). The scale bar represents 2 substitutions/base position.
Plate 2. Inhibition of *Macrophomina phaseolina* by *Bacillus subtilis* strain SGB1 under in vitro studies

Effective endogenous isolates (SGB 1) against *Macrophomina phaseolina*

Non effective endogenous isolates against *Macrophomina phaseolina*

Control
Plate 3. Inhibition of *Fusarium oxysporum* by *Bacillus tequilensis* strain SGB2 under in vitro studies

Treated with *Bacillus tequilensis*

Effective endogenous isolates (SGB 2) against *Fusarium oxysporum*

Non effective endogenous isolates against *Fusarium oxysporum*

Control
Inhibition of different bacterial isolates against *Macrophomina phaseolina* and *Fusarium oxysporum*

Bacterial isolates of *B. subtilis* and *B. tequilensis* were tested against pathogen of *M. phaseolina* and *F. oxysporum* (Table 5) (Plate 2). The bacterial isolates of *B. subtilis* recorded the least mycelial growth (45.00 mm) against *M. phaseolina* followed by *B. tequilensis* (50.00 mm). Mycelial growth of the control was 90 mm. The least mycelial growth of *F. oxysporum* was recorded in treatment with *B. subtilis* (63.00 mm) and *B. tequilensis* (69.00 mm) (Plate 3). The percentage inhibition over control against *M. phaseolina* and *F. oxysporum* was 44.44 and 30.00 per cent respectively. The application of *B. subtilis* recorded maximum inhibition zone of 13.00 mm for *M. phaseolina*, and 9.00 mm for *F. oxysporum* is having the potential to produce more than two dozen antimicrobial active compounds and are mostly antibiotic like peptides. Many of the potent antimicrobial compounds of *B. subtilis* like subtilin, subilosin, basilysin, surfactins are biosynthesized upon sporulation of *B. subtilis* (Stein, 2005).

In conclusion, talc-based powder formulation of *Bacillus* spores may be effective and eco-friendly management of thrips and root rot disease of mulberry plants.

**Further research**

1. Better understanding of silkworm gut microbes function by using molecular and systems-level analysis
2. Insect symbionts would aid to discover novel biocatalysts for biomass deconstruction and develop innovative strategies for pest and disease management
3. Novel antimicrobial protein identification would be helped to biomedical science

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**References**


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